

Review

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Review

Application of Different Echocardiographic Parameters in Sepsis-Induced Cardiomyopathy

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Abstract: Sepsis-induced cardiomyopathy (SICM) may be defined as a non-ischemic cardiac dysfunction associated with sepsis. SICM is characterized by a decrease in left ventricular contractility, ultimately associated with left ventricular dilation, with or without right ventricular dysfunction. Echocardiography stands as the current gold standard in diagnosis of SICM. Left ventricular ejection fraction (LVEF) is the most frequently utilized parameter for evaluating left ventricular systolic function, but some traditional parameters, including LVEF, are dependent on cardiac preload and afterload, limiting their clinical application. Advanced echocardiography techniques, such as speckle-tracking analysis, have the potential to diagnose and evaluate myocardial dysfunction even in the early phases of sepsis, facilitating risk stratification for proactive personalized treatment of patients. This article reviews the progress in the application of various echocardiographic parameters in SICM.

Keywords: sepsis-induced cardiomyopathy; echocardiography; application; research progress

1. Introduction

Sepsis-induced cardiomyopathy (SICM) is a reversible acute myocardial dysfunction unrelated to myocardial ischemia and represents a component of multiorgan failure caused by sepsis and septic shock [1]. The prevalence of SICM ranges from 18% to 40%, or even 70% in some reports [2]. The mortality rate of SICM is as high as 70–90%, which is two to three times higher than that of sepsis patients without cardiac involvement [3]. SICM is clinically characterized by a sharp decrease in left ventricular contractility, which may be accompanied by left ventricular dilation, with or without right ventricular failure. Echocardiography stands as a widely used and essential tool for the diagnosis and prognostic evaluation of SICM, assessing myocardial systolic and diastolic function, and changes in ventricular chambers in patients with sepsis. Advanced ultrasound techniques such as three-dimensional echocardiography, speckle-tracking echocardiography (STE), color or spectral Doppler imaging, and tissue Doppler imaging (TDI) provide more detailed insights into cardiac function and hemodynamics in SICM [1]. Each hemodynamically unstable patient should undergo critical ultrasonography for evaluation [4]. A recent study has demonstrated that cardiac ultrasound assessment in patients with sepsis facilitates hemodynamic management, enabling earlier withdrawal of vasopressors and reducing 28-day mortality [5]. This article aims to review the progress in the application of various echocardiographic parameters in SICM.

2. Parameters Reflecting Left Ventricular Systolic Function

There is still no consensus on the definition of SICM, and it is generally believed that left ventricular ejection fraction (LVEF) is a sign of SICM. Several indicators that assess left ventricular systolic function, namely LVEF, stroke volume (SV), and cardiac output (CO), are highly dependent

on both preload and afterload of the heart. These indicators simultaneously reflect the extent of fluid resuscitation/vascular leakage (i.e., preload) and vasoparalysis/responsiveness to vasoactive agents (i.e., afterload), making it difficult to distinguish whether the observed dysfunction is caused by myocardial dysfunction or hemodynamic disturbances during shock [6,7]. A low LVEF (< 50%) determined solely during sepsis does not possess prognostic value for SICM [8]. TDI and STE, which consider the loading conditions of the cardiovascular system, such as afterload-dependent CO or ventriculoarterial coupling, are promising ultrasonic methods [9].

2.1. Left Ventricular Ejection Fraction

As an indicator of left ventricular systolic function, LVEF is the first echocardiographic parameter for diagnosing SICM [10]. Typically, $LVEF \leq 50\%$ and the existence of left ventricular dilation are the diagnostic criteria for SICM [11]. Based on LVEF, left ventricular dysfunction can be classified into mild abnormality (LVEF between 41% and 51%), moderate abnormality (LVEF between 30% and 40%), and severe abnormality (LVEF below 30%) [12]. Bedside assessment of LVEF is relatively easy. However, LVEF is not a sensitive indicator of left ventricular systolic function. Juangzhen et al. [13] found no significant difference in initial LVEF between sepsis survivors and nonsurvivors. The heart's adaptive response to acute reductions in left ventricular systolic function is ventricular dilation, which maintains CO through the Starling mechanism [14]. This adaptive response may be even more crucial than LVEF. LVEF may overestimate systolic function in cases of severe infectious vasodilation, leading to underdiagnosis of SICM. The reduction in afterload caused by distributive shock may pseudo-normalize LVEF, and a patient with "normal LVEF" in severe shock (vasodilation) may be in a worse condition than a patient with "low LVEF" but no shock [15]. It is important that LVEF cannot detect early changes in SICM and may have neither diagnostic nor predictive value for SICM prognosis [1]. Assessment of myocardial function in sepsis needs to consider ventriculoarterial coupling (reduced afterload in early sepsis), which should be reassessed after initial fluid resuscitation and the use of vasoactive agents [16]. Additionally, when reporting LVEF in critically ill patients, it is recommended to simultaneously report the severity of shock and the use of vasopressors and positive inotropic agents.

2.2. SV and CO

Both SV and CO can be calculated by measuring the diameter of the left ventricular outflow tract and the velocity–time integral. SV and CO are also influenced by cardiac preload and afterload. The presence of low systemic vascular resistance (SVR) may falsely elevate the measured CO, and CO does not necessarily reflect intrinsic cardiomyocyte function/contractility, thus normal CO does not exclude the presence of SICM [15].

2.3. Peak Systolic Velocity of the Mitral Annulus

The peak systolic velocity (s') measured at the mitral annulus via TDI is another suitable surrogate for assessing left ventricular systolic function. The s' reflects left ventricular systolic function and correlates with LVEF. Compared with LVEF, s' exhibits less dependence on loading conditions. However, a meta-analysis encompassing 13 studies did not reveal any significant difference in s' values between SICM survivors and nonsurvivors [17]. The measurement of s' is also susceptible to angle limitations, as it involves a unidirectional (longitudinal) and single-segment (one-dimensional) assessment. The feasibility of s' in critically ill patients is approximately 62% [18].

2.4. Global Longitudinal Strain of the Left Ventricle

STE was first described in 2004. Given that it is minimally influenced by cardiac load and myocardial compliance, it stands as one of the most accurate ultrasonic methods for assessing myocardial function in various cardiac conditions, including SICM [1]. Using a non-Doppler automated algorithm, STE tracks selected myocardial segments throughout the cardiac cycle via the displacement of acoustic "speckles." The displacement of myocardial speckles along the

longitudinal axis represents the contractility of the heart from base to apex [15]. Among the measures of cardiac function using STE, global longitudinal strain (GLS) exhibits the highest level of consistency and reproducibility [1]. At present, left ventricular GLS, measured by STE, is considered more sensitive and specific than LVEF in diagnosing myocardial dysfunction and may serve as a robust parameter for SICM risk stratification and prognostic evaluation. GLS represents the ratio of the maximum change in myocardial longitudinal length during systole to the original length during diastole, with a normal range of -17% to -23% . A higher negative value indicates better performance [15]. A decrease in the negative value of GLS can signify more subtle alterations in myocardial function in patients with septic shock, enabling the detection of left ventricular systolic dysfunction even before a decline in LVEF becomes evident. The advantage of speckle tracking lies in its resistance to the pseudo-normalization of LVEF caused by reduced afterload [15]. According to Ng et al. [19], patients with septic shock exhibited more myocardial damage than those with sepsis alone (GLS of -18.3% and -14.5% , respectively), despite normal LVEF in both groups. The same authors also demonstrated the reversibility of SICM, with GLS values of -14.5% at diagnosis and -16.0% upon recovery ($P = 0.010$) [19]. GLS, independent of LVEF, can predict cardiovascular outcomes and provide prognostic information. Poorer GLS values in patients with severe sepsis and septic shock correlate with higher mortality rates [20]. However, the limitation of GLS lies in its reliance on good imaging quality, which may increase costs. Additionally, the reliability and accuracy of this method are influenced by various external factors, such as artifacts and noise. While GLS shows promising potential for the diagnosis and prognostic assessment of SICM, large-scale studies are needed to determine its clinical value.

2.5. Mitral Annular Plane of Systolic Excursion

Mitral annular plane of systolic excursion (MAPSE) stands as a promising assessment tool for SICM. In a 2018 study, MAPSE emerged as the sole statistically significant predictor of mortality [21]. The advantages of MAPSE include its ease of acquisition and its similarity to GLS, albeit without the need for speckle tracking or Doppler. Furthermore, MAPSE is easily reproducible and may be a useful measure of left ventricular systolic function for SICM assessment. However, its limitations include the potential interference of local wall motion abnormalities, calcification, and prosthetic valves, which may hinder the accuracy of measurements [22].

3. Parameters Reflecting Left Ventricular Diastolic Function

In patients with septic shock, especially those receiving large amounts of fluid resuscitation, an elevation in end-diastolic volume is common, potentially leading to adverse outcomes [2]. Similar to left ventricular systolic function, variations in definitions and lack of consensus on diagnostic techniques complicate the diagnosis of left ventricular diastolic dysfunction [23]. The early diastolic peak velocity of the mitral annulus (e') and the early diastolic peak velocity of mitral blood flow (E), detected by TDI, are considered key indicators of left ventricular diastolic dysfunction and reliable parameters for predicting mortality in SICM patients [24]. The e' is one of the least load-dependent measures of left ventricular diastolic dysfunction. The E/e' ratio correlates with left ventricular end-diastolic pressure, and a high E/e' ratio indicates elevated left ventricular end-diastolic pressure and low compliance. However, in patients with SICM, the correlation between the E/e' ratio and compliance is not as strong as in congestive heart failure, making it an imperfect surrogate for left ventricular end-diastolic pressure. In a meta-analysis, e' was found to be relatively independent of preload, and mortality in severe sepsis patients was associated with lower e' and higher E/e' ratio [25]. Lanspa et al. [26] introduced a simplified definition of left ventricular diastolic dysfunction in sepsis patients, based on $e' < 8$ cm/s and changes in E/e' ratio (≤ 8 as grade I, $8-13$ as grade II, and ≥ 13 as grade III). Using this approach, 87% of patients with severe sepsis or septic shock were identified as having diastolic dysfunction [26]. A limitation of the E/e' ratio is that local wall motion abnormalities, mitral valve disease, age, mechanical ventilation, and pericardial disease may affect its accuracy [27]. The e' wave may lead to an overestimation of the severity of diastolic dysfunction. In addition, in hyperdynamic CO, mitral annular velocity is influenced by the heart rate [2].

4. Parameters Reflecting Right Ventricular Function

Although the definition of SICM is based on left ventricular systolic dysfunction, both ventricles may be affected [28]. In a meta-analysis including 1373 patients with sepsis and septic shock, the incidence of right ventricular dysfunction was 35% [29]. Right ventricular dysfunction is associated with longer stays in the intensive care unit and higher risks of early and long-term mortality [30,31]. Right ventricular dysfunction involves decreased right ventricular ejection fraction and reduced dilation, often related to left ventricular systolic and/or diastolic dysfunction. The correlation between right ventricular dysfunction and adverse outcomes may be a false positive [32]. The complex geometry of the right ventricle makes its assessment difficult, and the use of tricuspid annular plane systolic excursion (TAPSE) or S wave for right ventricular assessment is limited to longitudinal assessment [16].

4.1. TAPSE

TAPSE is an indirect indicator for evaluating right ventricular function by describing the shortening from the apex to the base of the heart. It represents the simplest and most reproducible measurement method for assessing right ventricular function. A TAPSE value < 17 mm suggests abnormal right ventricular function and is linked to heightened illness severity and mortality in SICM [33]. However, a 2020 study by Lahham et al. [34] did not find a correlation among severe sepsis, septic shock, and TAPSE values. Vieillard-Baron et al. [35] defined right ventricular failure as right ventricular dilation (right ventricular/left ventricular end-diastolic area ≥ 0.6) and systemic congestion (central venous pressure ≥ 8 mm Hg). Based on this definition, 42% of 282 patients with septic shock exhibited right ventricular dysfunction, while 63.5% of the patients with right ventricular dysfunction had normal TAPSE values [35]. Therefore, further large-scale randomized controlled trials are needed to provide accurate data on TAPSE as a prognostic tool for SICM.

4.2. GLS of the Right Ventricle

The right ventricular GLS measured by STE may be a promising parameter for detecting right ventricular dysfunction, although the correlation between right ventricular strain and TAPSE or other parameters used to assess right ventricular function is moderate [16].

5. Parameters Reflecting the Overall Ventricular Function

SICM can damage the left ventricle, right ventricle, or both. The myocardial performance index (MPI), also known as the Tei index, is a Doppler-derived index. It is calculated using the following formula: $MPI = (\text{ventricular isovolumic contraction time} + \text{ventricular isovolumic relaxation time}) / \text{ejection time}$. A lower MPI indicates a better prognosis. A 2019 study by Nizamuddin et al. [36] showed that deterioration in MPI over 24 hours was linked to a significant increase in 90-day mortality rate. The advantage of MPI lies in its ability to simultaneously reflect myocardial systolic and diastolic functions. Unlike ejection fraction, MPI is independent of preload, heart rate, and ventricular anatomy. However, due to reduced left ventricular afterload during sepsis, there may be variations in MPI measurements, thereby reducing the accuracy of MPI measurements. Currently, validation studies on this method are limited, and further large-scale trials are needed to determine the value of MPI in assessing the prognosis of SICM.

6. Other Parameters

In addition to assessing the function and size of the left and right ventricles, echocardiography can also provide insights into the condition of the pericardium and large blood vessels, which is crucial for ruling out other differential diagnoses of SICM, such as sepsis-related Takotsubo cardiomyopathy, pericardial effusion, aortic dissection, and acute coronary syndrome [15]. The diameter and collapsibility of the inferior vena cava, as well as the B-line quantification from lung ultrasound, represent promising surrogate markers for right ventricular function in SICM and warrant further investigation.

7. Conclusions

In summary, SICM is increasingly recognized as a major dangerous complication of sepsis and septic shock, which has a significant effect on patient prognosis. In addition to compromising left ventricular systolic function, patients with SICM also experience left ventricular diastolic dysfunction and right ventricular involvement. Although echocardiography plays a pivotal role in the diagnosis, treatment, and prognosis of SICM, there is currently no single reliable and universally applicable echocardiographic parameter for the diagnosis of SICM [37]. Further clinical studies with larger sample sizes are required to explore the clinical application value of different echocardiographic parameters and new echocardiographic techniques in SICM.

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References

1. Lima, M. R.; Silva, D., Septic cardiomyopathy: a narrative review. *Rev Port Cardiol* **2023**, *42*, (5), 471-481.
2. Carbone, F.; Liberale, L.; Preda, A.; Schindler, T. H.; Montecucco, F., Septic cardiomyopathy: from pathophysiology to the clinical setting. *Cells* **2022**, *11*, (18), 2833.
3. Liu, S.; Chong, W., Roles of lncRNAs in regulating mitochondrial dysfunction in septic cardiomyopathy. *Front Immunol* **2021**, *12*, 802085.
4. Vieillard-Baron, A.; Millington, S. J.; Sanfilippo, F.; Chew, M.; Diaz-Gomez, J.; McLean, A.; Pinsky, M. R.; Pulido, J.; Mayo, P.; Fletcher, N., A decade of progress in critical care echocardiography: a narrative review. *Intensive Care Med* **2019**, *45*, (6), 770-788.
5. Feng, M.; McSparron, J. I.; Kien, D. T.; Stone, D. J.; Roberts, D. H.; Schwartzstein, R. M.; Vieillard-Baron, A.; Celi, L. A., Transthoracic echocardiography and mortality in sepsis: analysis of the MIMIC-III database. *Intensive Care Med* **2018**, *44*, (6), 884-892.
6. Tullo, G.; Candelli, M.; Gasparrini, I.; Micci, S.; Franceschi, F., Ultrasound in sepsis and septic shock: from diagnosis to treatment. *J Clin Med* **2023**, *12*, (3), 1185.
7. Geri, G.; Vignon, P.; Aubry, A.; Fedou, A. L.; Charron, C.; Silva, S.; Repessé, X.; Vieillard-Baron, A., Cardiovascular clusters in septic shock combining clinical and echocardiographic parameters: a post hoc analysis. *Intensive Care Med* **2019**, *45*, (5), 657-667.
8. Sevilla Berrios, R. A.; O'Horo, J. C.; Velagapudi, V.; Pulido, J. N., Correlation of left ventricular systolic dysfunction determined by low ejection fraction and 30-day mortality in patients with severe sepsis and septic shock: a systematic review and meta-analysis. *J Crit Care* **2014**, *29*, (4), 495-9.
9. Beesley, S. J.; Weber, G.; Sarge, T.; Nikravan, S.; Grissom, C. K.; Lanspa, M. J.; Shahul, S.; Brown, S. M., Septic Cardiomyopathy. *Critical Care Medicine* **2018**, *46*, (4), 625-634.
10. Khalid, N.; Patel, P. D.; Alghareeb, R.; Hussain, A.; Maheshwari, M. V., The effect of sepsis on myocardial function: a review of pathophysiology, diagnostic criteria, and treatment. *Cureus* **2022**, *14*, (6), e26178.
11. Yang, F.; Zhao, L. N.; Sun, Y.; Chen, Z., Levosimendan as a new force in the treatment of sepsis-induced cardiomyopathy: mechanism and clinical application. *J Int Med Res* **2019**, *47*, (5), 1817-1828.
12. Lang, R. M.; Badano, L. P.; Mor-Avi, V.; Afilalo, J.; Armstrong, A.; Ernande, L.; Flachskampf, F. A.; Foster, E.; Goldstein, S. A.; Kuznetsova, T.; Lancellotti, P.; Muraru, D.; Picard, M. H.; Rietzschel, E. R.; Rudski, L.; Spencer, K. T.; Tsang, W.; Voigt, J. U., Recommendations for cardiac chamber quantification by

- echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging. *Eur Heart J Cardiovasc Imaging* **2015**, 16, (3), 233-70.
13. Li, J.; Ning, B.; Wang, Y.; Li, B.; Qian, J.; Ren, H.; Zhang, J.; Hu, X., The prognostic value of left ventricular systolic function and cardiac biomarkers in pediatric severe sepsis. *Medicine (Baltimore)* **2019**, 98, (13), e15070.
 14. Habimana, R.; Choi, I.; Cho, H. J.; Kim, D.; Lee, K.; Jeong, I., Sepsis-induced cardiac dysfunction: a review of pathophysiology. *Acute Crit Care* **2020**, 35, (2), 57-66.
 15. L'Heureux, M.; Sternberg, M.; Brath, L.; Turlington, J.; Kashiouris, M. G., Sepsis-induced cardiomyopathy: a comprehensive review. *Curr Cardiol Rep* **2020**, 22, (5), 35.
 16. Boissier, F.; Aissaoui, N., Septic cardiomyopathy: Diagnosis and management. *J Intensive Med* **2022**, 2, (1), 8-16.
 17. Sanfilippo, F.; Huang, S.; Messina, A.; Franchi, F.; Oliveri, F.; Vieillard-Baron, A.; Cecconi, M.; Astuto, M., Systolic dysfunction as evaluated by tissue Doppler imaging echocardiography and mortality in septic patients: a systematic review and meta-analysis. *J Crit Care* **2021**, 62, 256-264.
 18. Boissier, F.; Razazi, K.; Seemann, A.; Bedet, A.; Thille, A. W.; de Prost, N.; Lim, P.; Brun-Buisson, C.; Mekontso Dessap, A., Left ventricular systolic dysfunction during septic shock: the role of loading conditions. *Intensive Care Med* **2017**, 43, (5), 633-642.
 19. Ng, P. Y.; Sin, W. C.; Ng, A. K.; Chan, W. M., Speckle tracking echocardiography in patients with septic shock: a case control study (SPECKSS). *Crit Care* **2016**, 20, (1), 145.
 20. Sanfilippo, F.; Corredor, C.; Fletcher, N.; Tritapepe, L.; Lorini, F. L.; Arcadipane, A.; Vieillard-Baron, A.; Cecconi, M., Left ventricular systolic function evaluated by strain echocardiography and relationship with mortality in patients with severe sepsis or septic shock: a systematic review and meta-analysis. *Crit Care* **2018**, 22, (1), 183.
 21. Havaladar, A. A., Evaluation of sepsis induced cardiac dysfunction as a predictor of mortality. *Cardiovasc Ultrasound* **2018**, 16, (1), 31.
 22. Zhang, H. M.; Wang, X. T.; Zhang, L. N.; He, W.; Zhang, Q.; Liu, D. W., Left ventricular longitudinal systolic function in septic shock patients with normal ejection fraction: a case-control study. *Chin Med J (Engl)* **2017**, 130, (10), 1169-1174.
 23. Oh, J. K.; Miranda, W. R.; Bird, J. G.; Kane, G. C.; Nagueh, S. F., The 2016 Diastolic Function Guideline: Is it Already Time to Revisit or Revise Them? *JACC Cardiovasc Imaging* **2020**, 13, (1 Pt 2), 327-335.
 24. Ravikumar, N.; Sayed, M. A.; Poonsuph, C. J.; Sehgal, R.; Shirke, M. M.; Harky, A., Septic cardiomyopathy: from basics to management choices. *Curr Probl Cardiol* **2021**, 46, (4), 100767.
 25. Sanfilippo, F.; Corredor, C.; Arcadipane, A.; Landesberg, G.; Vieillard-Baron, A.; Cecconi, M.; Fletcher, N., Tissue Doppler assessment of diastolic function and relationship with mortality in critically ill septic patients: a systematic review and meta-analysis. *Br J Anaesth* **2017**, 119, (4), 583-594.
 26. Lanspa, M. J.; Gutsche, A. R.; Wilson, E. L.; Olsen, T. D.; Hirshberg, E. L.; Knox, D. B.; Brown, S. M.; Grissom, C. K., Application of a simplified definition of diastolic function in severe sepsis and septic shock. *Crit Care* **2016**, 20, (1), 243.
 27. Lanspa, M. J.; Shahul, S.; Hersh, A.; Wilson, E. L.; Olsen, T. D.; Hirshberg, E. L.; Grissom, C. K.; Brown, S. M., Associations among left ventricular systolic function, tachycardia, and cardiac preload in septic patients. *Ann Intensive Care* **2017**, 7, (1), 17.
 28. Zhang, H.; Liu, D., Sepsis-related cardiomyopathy: not an easy task for ICU physicians. *J Intensive Med* **2022**, 2, (4), 257-259.
 29. Vallabhajosyula, S.; Shankar, A.; Vojjini, R.; Cheungpasitporn, W.; Sundaragiri, P. R.; DuBrock, H. M.; Sekiguchi, H.; Frantz, R. P.; Cajigas, H. R.; Kane, G. C.; Oh, J. K., Impact of right ventricular dysfunction on short-term and long-term mortality in sepsis: a meta-analysis of 1,373 patients. *Chest* **2021**, 159, (6), 2254-2263.
 30. Kim, J. S.; Kim, Y. J.; Kim, M.; Ryoo, S. M.; Kim, W. Y., Association between right ventricle dysfunction and poor outcome in patients with septic shock. *Heart* **2020**, 106, (21), 1665-1671.
 31. Lanspa, M. J.; Cirulis, M. M.; Wiley, B. M.; Olsen, T. D.; Wilson, E. L.; Beesley, S. J.; Brown, S. M.; Hirshberg, E. L.; Grissom, C. K., Right Ventricular Dysfunction in Early Sepsis and Septic Shock. *Chest* **2021**, 159, (3), 1055-1063.
 32. Dugar, S. P.; Vallabhajosyula, S., Right ventricle in sepsis: clinical and research priority. *Heart* **2020**, 106, (21), 1629-1630.

33. Ehrman, R. R.; Sullivan, A. N.; Favot, M. J.; Sherwin, R. L.; Reynolds, C. A.; Abidov, A.; Levy, P. D., Pathophysiology, echocardiographic evaluation, biomarker findings, and prognostic implications of septic cardiomyopathy: a review of the literature. *Crit Care* **2018**, *22*, (1), 112.
34. Lahham, S.; Lee, C.; Ali, Q.; Moeller, J.; Fischetti, C.; Thompson, M.; Saadat, S.; Fox, J. C., Tricuspid annular plane of systolic excursion (TAPSE) for the evaluation of patients with severe sepsis and septic shock. *West J Emerg Med* **2020**, *21*, (2), 348-352.
35. Vieillard-Baron, A.; Prigent, A.; Repesse, X.; Goudelin, M.; Prat, G.; Evrard, B.; Charron, C.; Vignon, P.; Geri, G., Right ventricular failure in septic shock: characterization, incidence and impact on fluid responsiveness. *Crit Care* **2020**, *24*, (1), 630.
36. Nizamuddin, J.; Mahmood, F.; Tung, A.; Mueller, A.; Brown, S. M.; Shaefi, S.; O'Connor, M.; Talmor, D.; Shahul, S., Interval changes in myocardial performance index predict outcome in severe sepsis. *J Cardiothorac Vasc Anesth* **2017**, *31*, (3), 957-964.
37. Lin, H.; Wang, W.; Lee, M.; Meng, Q.; Ren, H., Current status of septic cardiomyopathy: basic science and clinical progress. *Front Pharmacol* **2020**, *11*, 210.

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